4.1. SOIL STRUCTURE AND SOIL BIOLOGICAL INTERACTION IN THREE DIFFERENT AGRICULTURAL PRACTICES

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INTRODUCTION

Soil structure is a dynamic result of many biotic and abiotic factors and processes. Under natural conditions, the main soil structure-forming factors and processes are texture, soil organic matter, soil organisms, groundwater levels and weather. In cultivated land, the human impact, for example tillage, traffic, pesticides, fertilizers and manure, regulates the soil structure and its dynamics throughout the year (Fig.1).

At an experimental farm near Marknesse in the Noordoostpolder in the Netherlands, long-term experiments with agroecosystems are being carried out. The soil structure of the topsoils of three different agroecosystems were studied using micro-morphological and soil physical methods. For eighteen years or more the cultivation practice has remained the same, resulting in stabilized soil structures. The topsoils of the three farming systems show differences in soil structure, visible in the field and expressed by different sizes and grade of development of the aggregates, whether or not they include faunal excrements.

MATERIAL AND METHODS

Different systems of agricultural practices are carried out on adjoining sites on the same soils, viz. sedimentary calcareous sandy loams classified as Typic Fluvaquents (Soil Survey Staff, 1975) or as Calcaric Fluvisols (FAO-*Unesco*, 1974). In the three systems studied, the parent material had the same composition. The pH and $CaCO_3$ content and also the drainage and weather conditions were the same. Hence, differences in soil structure can only be attributed to tillage, organic matter and structure-forming soil organisms.

AGRICULTURAL PRACTICES

The three agricultural practices can be characterized as follows:

1) Conventional tillage, with a crop rotation of six years and the use of only inorganic fertilizers;

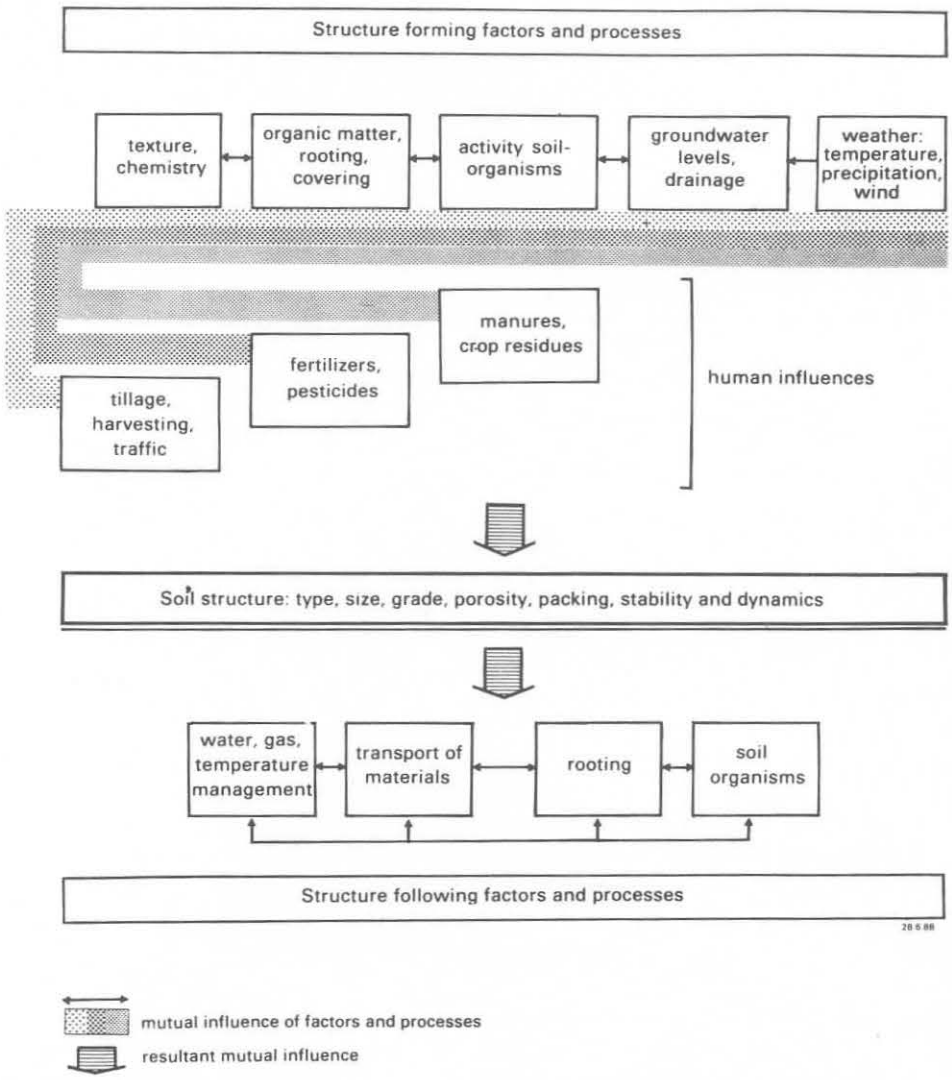

Fig. 1. Structure-forming and sructure-following factors and processes and their mutual relationships.

2) Ley farming, with a crop rotation of eight years, in which, in addition to the same crops as grown in the previous system, two separate years of ley with grassland are included. Farmyard and green manure are also applied.

3) Minimum tillage, with a crop rotation of six years. The same type and amount of inorganic fertilizers were applied as in system 1. The tillage depth for weed control was 5 cm instead of 20 cm used in the other two systems.

The six-year crop rotations were the same in the three systems. The crops were wheat, flax, seed potatoes, sugar beet, spring barley and ware potatoes. The supply of organic matter in the ley farming system amounted to 5280 kg ha^{-1} yr^{-1} on an average, compared with 3209 kg ha^{-1} yr^{-1} for the other systems. The organic matter content of the upper layer of the ley farming system was finally 0.5 per cent higher at 2.8 per cent than in the other two systems. The higher level of organic matter in the ley farming system can be attributed mainly to the application of farmyard manure, as the other organic fertilizers are easily decomposable (Kooistra *et al.*, in prep.).

METHODS

To study the soil structure in more detail, undisturbed soil samples were taken for micromorphological investigation. They were air-dried and processed into thin sections following the methods described by Jongerius and Heintzberger (1975). Soil columns, carefully cut in the field, were percolated with 10 per cent methylene blue solution to study the continuity of the pore system and to determine soil physical properties, viz. moisture retention curves and hydraulic conductivities. The methods used are described by Bouma *et al.* (1977) and Kooistra *et al.* (1984). All samples were collected on 30.5.85 and 31.5.85 when sugar beet crop was grown.

RESULTS

Micromorphological results

Soil structure was studied in thin sections by analyses of occurring voids and aggregates. In the thin sections studied, three main groups of voids and aggregates were present: (1) Tillage voids and aggregates, (2) Root channels, and (3) Voids and aggregates produced by soil fauna.

Tillage voids and aggregates

In cultivated land, aggregates formed by tillage operations are not bordered by natural cracks. They rarely accommodate each other and irregular voids occur between them. The aggregates as well as the voids between them are not stable and change quickly. By natural setting, but also by new tillage operations and machinery traffic over the field, the soil becomes denser. The individual aggregates are difficult to distinguish and the voids between them become smaller and isolated.

Root channels

Roots produce channels by the exertion of pressure on the soil constituents. Roots also follow existing voids and enlarge them locally. In arable land, in the topsoil, they follow mainly the tillage voids which they modify during their growth, soil setting and tillage and traffic operations. Below the tilled layer, they also follow faunal channels and natural

cracks. Root channels are very stable which, when not disturbed, are continuous over relatively long distances. In Table 1 the effect of the rooting in the different farming systems is given.

Table 1. Effect of rooting on soil structure at different farming systems

farming systems	voids with roots			
	root channels	modified voids	→	original voids
conventional	—	×		tillage
ley farming	(×)	×		tillage, (faunal)
minimum tillage	×	×		(tillage), faunal

(×) = few; × = common

Voids and aggregates produced by soil fauna

The soil fauna produces all kinds of voids, including channels. Channels can be made by the exertion of pressure on the soil particles as done by roots, but also by digging and removal of the loose particles and by consumption. Channels produced by soil fauna are less regular than root channels and can be more branched. Modification of existing voids' cracks, tillage voids and roots as well as faunal channels, by one or more groups of organisms occurred on a large scale. In all these voids excrements could be found partly or completely filling voids whereby new kinds of voids were created. Faunal voids, like root channels, are stable and often continuous over longer distances. A number of features due to faunal activities could be ascribed to specific groups of soil fauna based on type and size of channels, excrements and location. These groups were as follows:

A) *Mites and springtails*. These rarely produce their own channel systems, but enlarge locally existing voids. The excrements of mites are ellipsoidal to slightly cylindrical with regular, generally smooth surfaces and occur in loose clusters.They range between 80-150 µm in length and generally consist of unrecognizable fine particles of organic material and excrement of a species include fine-grained mineral material. The excrements of collembola are of the same shape, but with irregular rough surfaces. Their sizes range from 60-90 µm. They are composed of organic material, sometimes including a small amount of fine-grained mineral material and also occur in loose clusters.

B) *Enchytraeids*. They prefer to follow existing voids, but make channels at locations where the groundmass is less dense. In tilled layers, they are the contact zones between more or less amalgamated tillage aggregates. Enchytraeids feed on crop residues and decaying roots, which they fragment and consume. Their excrements resemble those of the springtails but are more cylindrical, larger in size and form spongy clusters of several mm in size. Excrements of enchytraeids can also contain fine-grained mineral material.

C) *Earthworms*. They produce channels which can be plastered and refilled with excrements. The diameters, lengths and depths reached depend on the size of the species and their feeding habits. Their excrements vary from ellipsoidal, short cylindrical to long cylindrical to threadlike forms. They always consist of mixtures of organic and mineral material. When single shaped excrements are produced they are often clustered and compressed by the animal.

In Fig. 2, examples of structure-forming activities of these faunal groups are given.

More effects of faunal activities were traced, but they were either not characteristic enough to be ascribed to one group due to modifications or were due to organisms, the

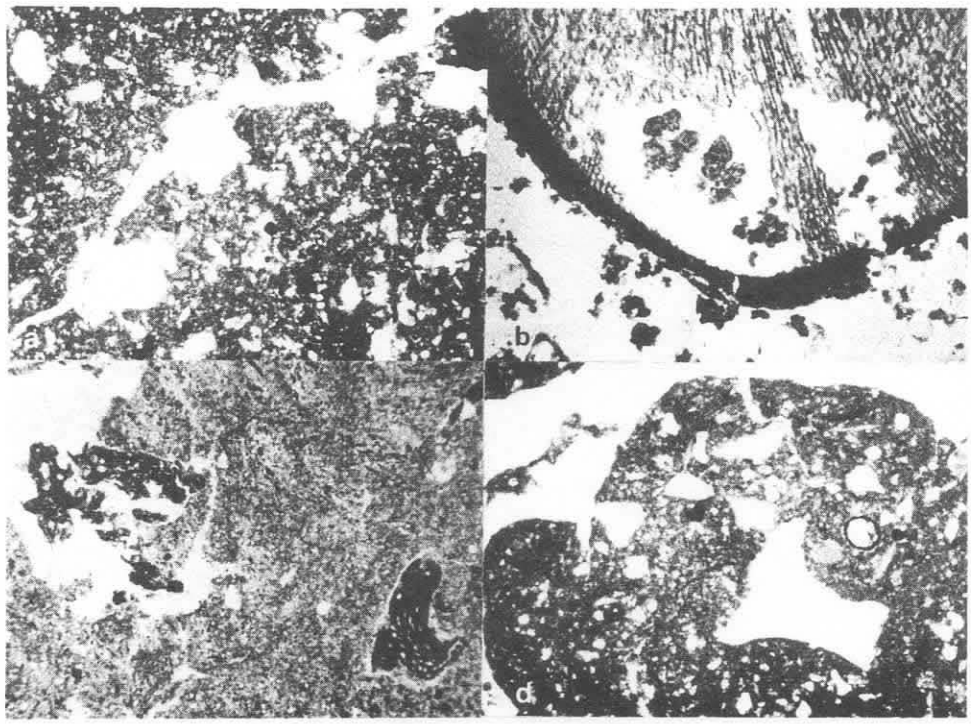

Fig. 2. Soil faunal activities as visible in thin sections. a. Local enlargement of a crack by mites; width 1200 μm; b. Root cross-section with consumption patterns of mites and collembolans, well-shaped mite excrements composed of internal cellular structure inside and smaller less well-shaped collembolan excrements of epidermis material inside and outside the epidermis; width 1 mm; c. Crop residues in the groundmass after ploughing; one piece fragmented and partly consumed by enchytraeids; width 5 mm; d. Clustered excrements of *Allolobophora chlorotica*; width 4 mm.

features of which are not well known, for example, beetle larvae. The effects of faunal activities observed in thin sections are not a measure for populations, as one species can have a larger structure-forming activity than others.

The effects of the identified soil fauna on the soil structure in the three agroecosystems are given in Table 2. Compared with conventional farming, the ley farming system contained more modified voids caused by mites and springtails, and excrements of the latter occurred. The effects of enchytraeids and earthworms were also greater. In the ley farming systems, more crop residues and remnants of green manure, on which these animals feed, were present. Worm channels and excrements occurred over the whole tilled layer, where excrements of *Allolobophera caliginosa* were clearly identified. The earthworm population consisted of *Allolobophora caliginosa, Lumbricus rubellus* and *A. rosea* (Marinissen, 1988). In addition, other effects of unidentified fauna were evident. In the minimum tillage system earthworms were lacking. They have not yet colonized this part of the farm after reclamation of the polder in 1943. The effects of mites, collembolans and enchytraeids were much greater here than in the ley farming system. The effect of unidentified species was more varied.

Quantitative data on the origin of voids in the upper 30 cm of the farming systems studied are given in Fig. 3. In addition, the total porosity of voids with diameters > 30 μm, i.e., the voids studied micromorphologically, is also presented. These data were

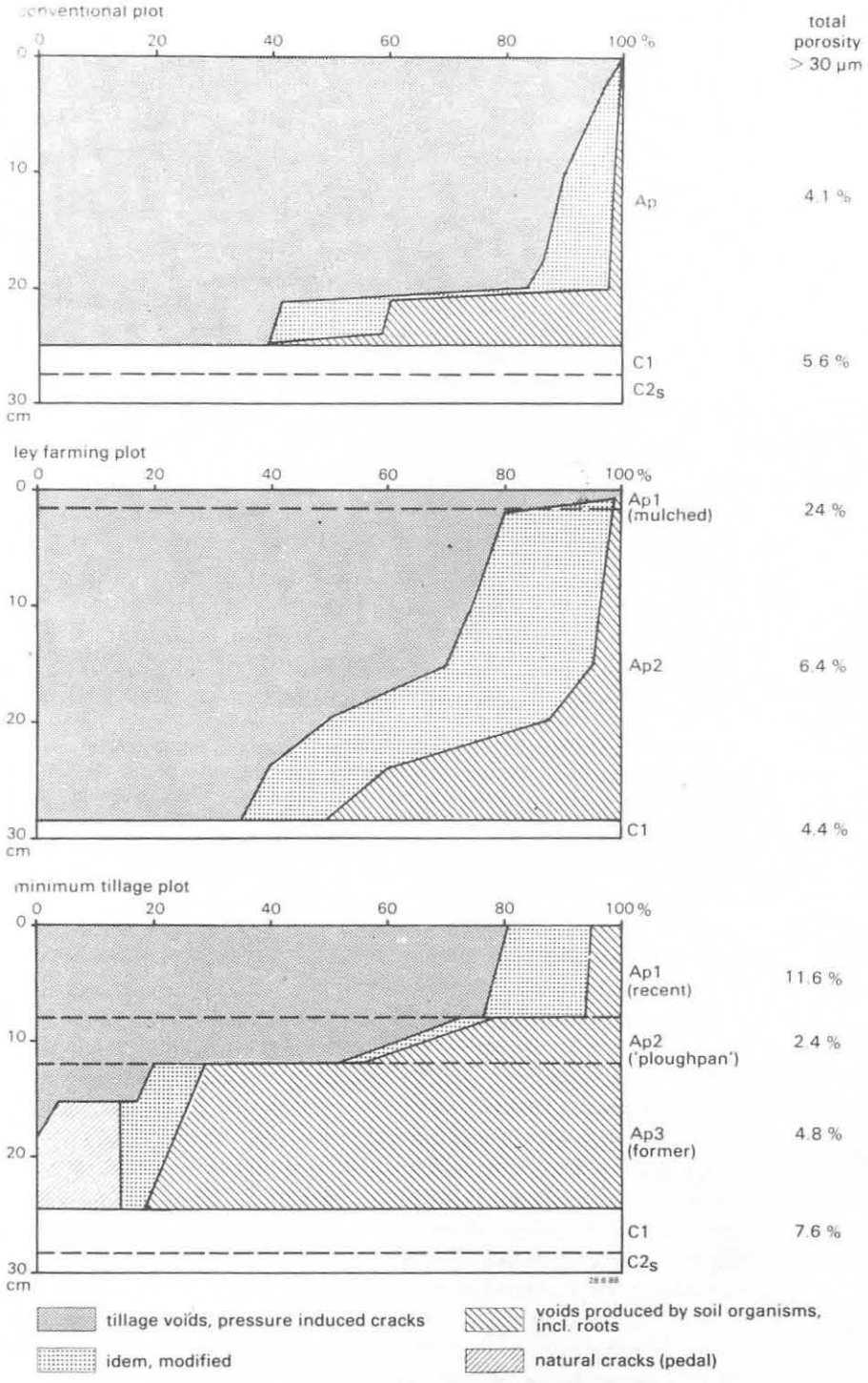

Fig. 3. Analyses and quantification of the structure-forming factors and processes of the first 30 cm of the three farming systems.

Table 2. Effect of soil fauna on soil structure at different farming systems

	Voids		Excrements		
	Primary	Modified	om	om/min	min
Conventional farming					
Mesofauna					
Acarina (mites)	–	(X)	–	–	–
Collembola (springtails)	–	(X)	–	–	–
Macrofauna					
Enchytraeidae (potworms)	–	X	X	–	–
Lumbricidae (earthworms)	X*	X	–	(X)	X
Other invertebrates	–	X	–	–	X
Ley farming					
Mesofauna					
Acarina	–	X	–	–	–
Collembola	–	X	X	–	–
Macrofauna					
Enchytraeidae	–	X	X	–	–
Lumbricidae	X	X	–	X	X
Other invertebrates	X	X	–	?	X
Minimum tillage					
Mesofauna					
Acarina	–	X	X	–	–
Collembola	–	X	X	–	–
Macrofauna					
Enchytraeidae	–	X	X	–	–
Lumbricidae	–	–	–	—	
Other invertebrates	X	X	–	–	–

om = organic matter; min = mineral matter;
– = not present; (X) = few; X = common;
*Only deeper than 21 cm, in former tilled layer

determined by image analyses from the thin sections. The modified voids are all voids which do not show their original shape. Faunal channels modified by other faunal species also belong to this group. In the conventional tillage system most voids were due to tillage operations. Up to 21 cm depth primary voids hardly occurred and, when present, were mainly faunal channels. The modified voids were tillage voids changed in shape by root or faunal activity. Below 21 cm depth, the limit of the tilled layer, the increase in biological voids was almost solely caused by worms. In the ley farming system, the proportion of tillage voids was about 10 per cent lower. The impact of the fauna was much greater and roots also produced primary channels. The differences in void distribution was quantitatively even more pronounced than in the ley farming system where in about 50 per cent more voids with diameters > 30 μm occurred than in the conventional tillage system. In the minimum tillage system the pattern changed clearly. Even below 8 cm depth, the actual Ap, tillage-induced voids occurred, as pressure-oriented horizontal cracks. Primary biological voids contributed a larger proportion. More primary root channels occurred than in the ley farming system, but the largest part was formed by the fauna. The total porosity of voids with diameters > 30 μm was low in the Ap2, indicating a compacted layer. Below that zone primary biological voids were dominant.

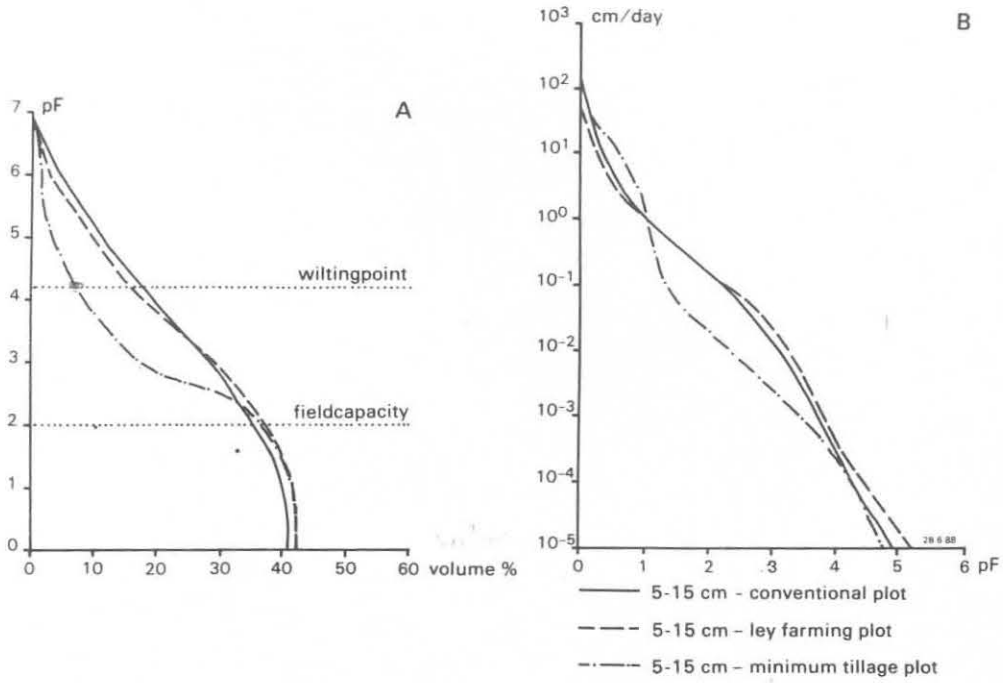

Fig. 4. Moisture retention characteristics (A) and hydraulic conductivities (B) of the topsoils of the three farming systems.

Soil physical results

The soil physical characteristics, in particular moisture retention curves and hydraulic conductivities, are largely determined by the diameters and continuity of the voids present. In Fig. 4, the moisture retention curves and hydraulic conductivities of the topsoils studied are shown. The moisture content of the soil in three systems was almost identical in the range from saturation to field capacity. The conventional system had the lowest capacity and the other two had almost the same. At higher pF values, the water-holding capacity in the minimum tillage system was clearly lower than that of the other two systems, the ley farming being slightly lower than the conventional one. The same trend occurred in the hydraulic conductivities. At saturation the conductivities were almost identical. At a small negative waterhead the conductivity of the minimum tillage system was slightly higher, but at higher negative pressures, $h > -10$ cm, was clearly lower than those in the other two systems. The ley farming system had a slightly higher conductivity at higher pF values.

The continuity of the voids can be made visible in thin sections. In undisturbed soil columns, all continuous voids develop blue-stained walls when percolated with a methylene-blue solution. These columns were cut into a number of horizontal slabs, from which thin sections for micromorphological studies were made. The stained voids in the thin sections could be examined separately with image analyses. The results are given in Fig. 5.

The total macroporosity, i.e. all voids > 30 μm in diameter, was lowest in the conventional tillage system, never exceeding 6 per cent in volume. At 18 cm depth less

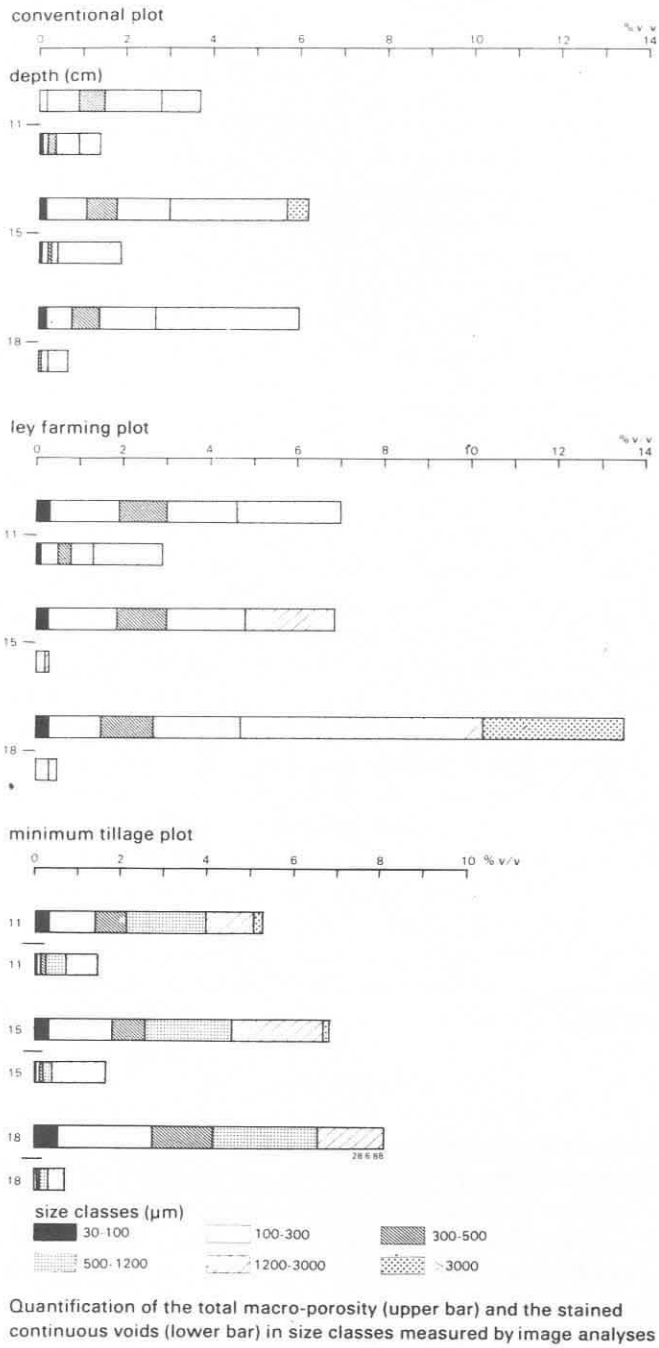

Fig. 5. Quantification of the total macroporosity (upper bar) and only the stained voids (lower bar) in size classes of the topsoils of the three farming systems measured by image analyses.

than 1 per cent had stained walls and were continuous throughout. All continuous voids were more than 300 μm in diameter. In the ley farming system, the macroporosity was in all cases greater than 6 per cent, strongly increasing with depth, especially in the size classes larger than 1200 μm in diameter. But in this case also, only 1 per cent of them were continuous. In the minimum tillage system the macroporosity was around 6%, increasing with depth. Here, size classes up to 300 μm in diameter were more numerous. Here again, only 1% of them were continuous. These results explain why the moisture retention curves were almost the same up to pF 2.0 and hydraulic conductivities did not differ more, in spite of the clear differences in type and quantity of the occurring voids.

CONCLUSIONS

In the three agricultural practices different soil structures and porosities occurred due to tillage operations and faunal activities. Plant roots did not contribute substantially. The difference between the conventional tillage system and the ley farming is due only to application of farmyard and green manures in addition to inorganic fertilizers. The organic manures stimulated the structure-forming soil fauna, especially earthworms, beetle larvae and enchytraeids. The minimum tillage system had a good macroporosity, comparable with the conventional tillage system, but built up by the soil fauna. Hence, the quantity of continuous voids is hardly greater than in the other two systems. Theoretically, one would expect the share of continuous voids to increase in the following order: conventional system < ley farming system < minimum tillage system. This was not found due to several reasons. The soil material studied is rather susceptible to slaking. In the ley farming system, part of the continuous worm channels, which form the additional group of continuous voids, are blocked by internal slaking. In the minimum tillage system on the other hand, earthworms producing large continuous channels are absent. Here, it is notable that smaller structure-forming soil animals were able to produce a more comparative soil porosity than in the conventional farming system with a higher structure stability.

In spite of the large differences in type, size and quantity of voids in the three agricultural practices used, the volume of the continuous voids was virtually the same. This explained the minor differences in soil physical parameters. The actual differences in voids present in the farming systems, however, will have a clear impact on the habitat of microorganisms, micro- and mesofauna, as well as on rooting patterns and turnover of organic matter.

SUMMARY

Soil structure is not a static property of soils but a dynamic result of many biotic and abiotic factors and processes. In the EEC there is increasing scope for research on efficient agricultural production at reduced inputs. Reduced input agricultural practices result in changes of soil structure as tillage operations are reduced, while soil biota increase their impact on soil structure formation. Effects of the meso- and macrofauna are studied in three different agroecosystems on the same young marine sandy loam in the Netherlands. Reducing tillage operations has resulted in the increased formation of channels of different kinds, and in modifications of other voids, mainly tillage voids. Because of this, more stable and continuous voids have resulted, influencing soil physical properties of the soil as conducting macrovoids, moisture retention curves and hydraulic conductivities.

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